

THE STRUCTURE OF DIFFUSION FLAMES

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16. Abstract The author's technique (1971) was used for treatment of instantaneous Töpler schlieren pictures in a study of the diffusion flame structure of plane hydrogen jets in laminar hydrogen-air flows in a rectangular 45 x 45-mm channel with vortex generators. Temperature inhomogeneity scales vs initial flow rates and hydrogen-air ratios were determined for the diffusion burning of hydrogen-air flows.			
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THE STRUCTURE OF DIFFUSION FLAMES

V. F. Sokolenko, R. S. Tyul'panov, and Yu. V. Ignatenko[†]

The combustion of a turbulent diffusion flame in a number of /566* practically important cases is characterized by the presence of clearly pronounced volume zones in which a chemical reaction takes place. Such a situation occurs due to the fact that in a turbulent flow the local values of velocity, pressure, and so forth vary according to a very complex law, which may be written with the use of some distribution functions ψ_i . If there are two flows, fuel and oxidizer, then the local concentration of these components are also described by certain functions ϕ_j . Without assigning an explicit form to the functions ψ_i and ϕ_j , it is however possible to confirm that there exist such local zones in a flow as can be determined at each given moment by a combination of such functions, the condition for the ignition and subsequent combustion in which are most favorable. A certain amount of studies are dedicated to this problem, however it is difficult to make a strict theoretical examination of such a problem at the present time. Experimental investigations in this direction have only just begun. In [1] it was discovered that the temperature nonuniformities, caused by chemical reaction for some diffusion hydrogen flames, are subject to statistical regularities; the correlation function is subject to an exponential dependence of the type $e^{-\xi/\Lambda_{\text{burn}}}$, where Λ_{burn} is the average scale of these nonuniformities, connected with the Lagrange scale of turbulence defined by the dependent.

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* Numbers in the right margin indicate pagination of the foreign text.

The present study is a direct continuation of these investigations, in which several types of diffusion planes were studied.

A schematic diagram of the apparatus and the method based on obtaining and analyzing simultaneous Töpler photographs of the structure of flames are described in [1]. Diffusion flames of hydrogen supplied from a two-dimensional jet from the wall and along the center of a 45 x 45 mm channel (Fig. 1) were investigated. Preliminarily the turbulence intensity field in the channels was studied in detail with the use of a "Diza" apparatus and the Lagrange turbulence scale by a diffusion method depending on the flow velocity. As the experiments showed, the turbulence intensity in a rough channel on cold modes of operation varies little with a change in flow velocity (self-similarity of this parameter is observed), but it is significantly higher than in a smooth channel, and the average Lagrange turbulence scale for /567

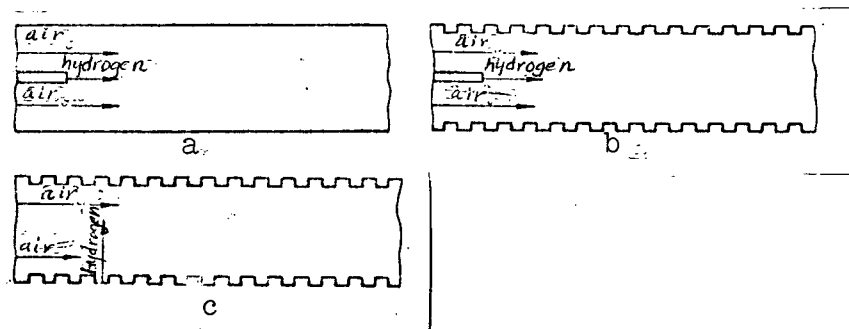


Fig. 1. Schematic depiction of the variance of diffusion flames studied.

- a- hydrogen supply along center, smooth channel;
- b- hydrogen supply along center, rough channel;
- c- hydrogen supply from wall, rough channel

each flow is 1.4-1.8 mm for the range of flow velocities studied of from 20-100 m/s. A turbulence intensity field was obtained

analogous to that measured earlier in such a channel with an LII thermal anamometer [2], however the absolute values of the pulsations proved to be somewhat higher. In some cases of the fuel feed into the airflow the fields of hydrogen burn-out were studied by two methods. The first—sampling the gas intake with a special cooling with subsequent analysis on the Khrome-3 chromatograph and calculation of the burn-out according to the change in concentrations of fuel and oxygen. The second—determining the burn-out

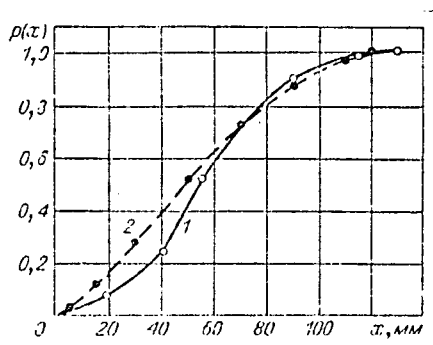


Fig. 2. Burn-out curve of a diffusion flame with a two-dimensional jet of hydrogen supplied along the center of a channel.

1- gas analysis; 2- photometering.

by photometering a photographic negative obtained with long exposure from the entire flame. The basic principle of the latter method and the experimental results of photometering homogeneous flames are contained in [3]. In the present investigation this method of determining flame burn-out is compared with the first, which is traditional for diffusion flames. Figure 2 shows a comparison of the burn-out curve $p(x)$ along the length of the flame x obtained by the two methods for one of the operating modes with the hydrogen supplied along the center of the channel. As is seen from the graph, there is a good agreement of the burn-out curves $p(x)$ at the final stages. Therefore the photometering method may

be used for determining the length of a diffusion plane, and it was used for this purpose in the following experiment.

If we consider the propagation of a diffusion flame as the propagation of a jet where the zone of chemical reaction is located in mathematical approximation along the line of stoichiometric oxidizer-fuel ratios, then the problem reduces to the solution of an ordinary system of gas dynamic equations. Given certain additional conditions the problem has a solution and on the basis of the calculation scheme proposed allows for the determination of the burn-out efficiency and several other parameters of the burning jet [4,5].

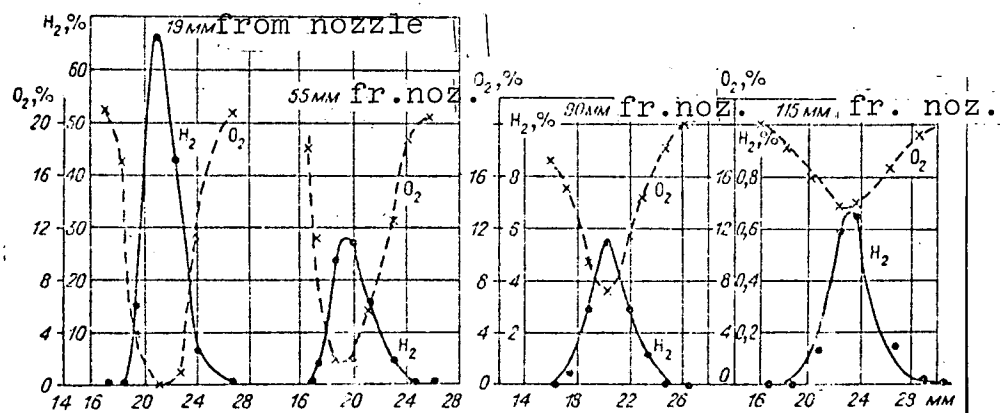
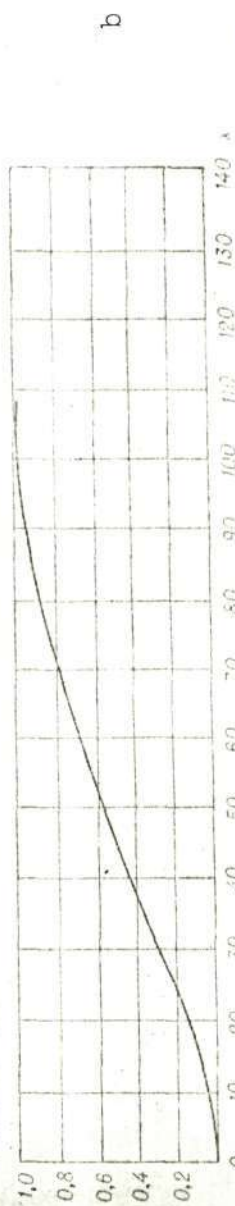


Fig. 3. Field of concentrations in the case of burning a planar hydrogen jet in air at different distances from the insertion of the jet.

Measurement of the fields of average concentrations of a burning jet in a turbulent wake actually shows that practically until complete burn-out of the fuel the fields of concentration are similar to the concentration profiles of a cold jet. In either case the fields of concentration are described by the curve of a normal Gauss distribution. Figure 3 shows the fields of volume concentration of H_2 and O_2 for one of the modes of /569



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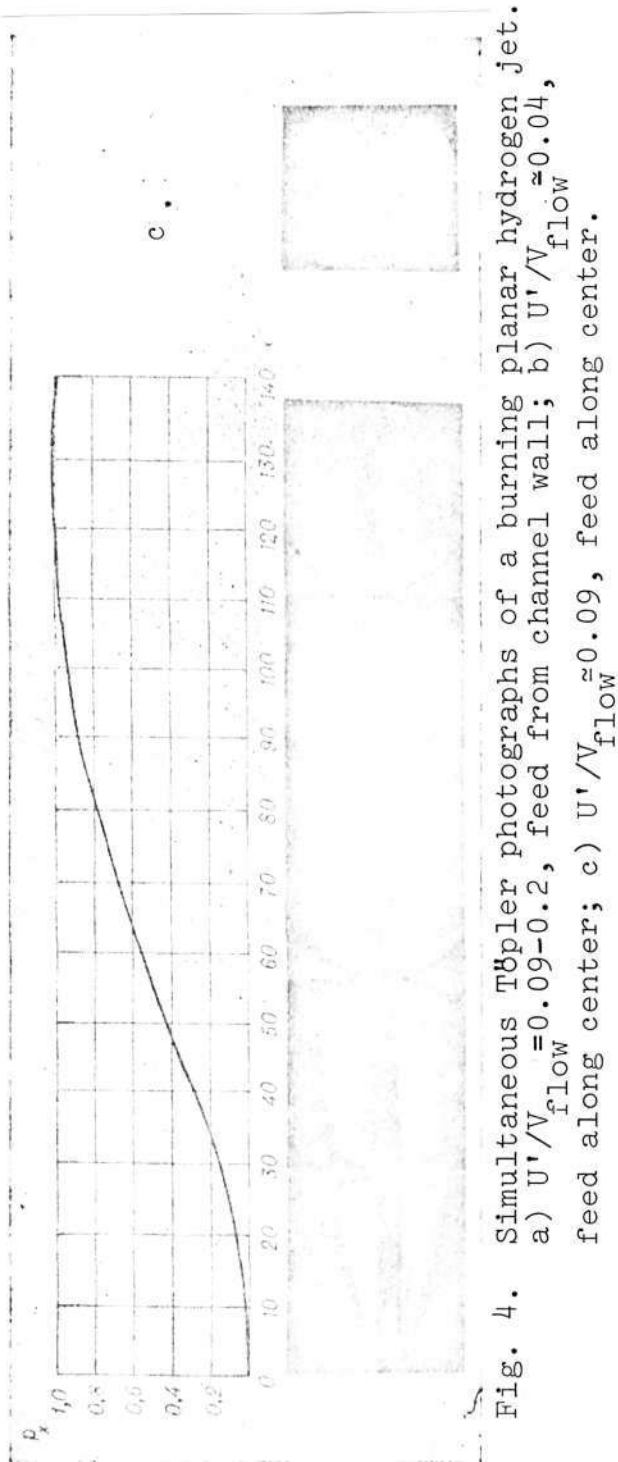


Fig. 4. Simultaneous Töpler photographs of a burning planar hydrogen jet. a) $U'/V_{\text{flow}} = 0.09-0.2$, feed from channel wall; b) $U'/V_{\text{flow}} \approx 0.04$, feed along center; c) $U'/V_{\text{flow}} \approx 0.09$, feed along center.

operation from the point of insertion of the H_2 jet until the complete consumption of the H_2 along the entire section. However such a change in the average concentration, indicating that the burn-out is subject to regular laws analogous to diffusion spreading with a certain effective coefficient of turbulent diffusion, still says nothing about the actual mechanism of combustion and, consequently, may include empirical constants not adequate to the internal mechanism.

As was stated initially, in a number of cases a burning jet of fuel, introduced into a flow, immediately forms localized zones where chemical reactions take place. The different types of diffusion flame, depicted in Fig. 1, were studied with the use of a Töpler IAB-451 and a streak camera in time-magnifier conditions (exposure time 10^{-6} sec); the real picture of the distribution zone with gradients of the index of refraction, caused by temperature changes as a result

of chemical reactions, was determined. With the feed of a planar burning hydrogen jet into a turbulent flow with a velocity close /570 to the flow velocity $V_{jet}/V_{flow} \approx 2$, and a turbulence intensity $U'/V_{flow} = 0.04$ (Fig. 4,b), and $U'/V_{flow} = 0.09$ (Fig. 4,c), the burning at short distances from the feed point takes place in a narrow region in the zone where the jet mixes with the flow. However in these conditions, which are comparatively unfavorable for the turbulent spread of a jet, already with a degree of burn-out $p(x) = 0.6-0.7$ the flame appears as separate localized zones of burning. Sequential photographs along the length of the flame (Fig. 4,c) show how the destruction of a clear boundary between the fuel and oxidizer begins, where chemical reactions take place.

With the feed of a planar hydrogen jet from the wall perpendicular to the flow and the turbulence intensity $U'/V_{flow} \approx 0.09-0.2$ the burning is immediately established in separate zones. A characteristic example of such a burning jet is depicted in Fig. 4,a where sequential Töpler photographs of a flame at different points along the axial coordinate x are shown. The latter variant of fuel feed has great practical value, and the structure of such a burning jet has been studied particularly carefully.

In these experiments the process of burning hydrogen in a channel on a fixed regime was photographed on sensitive film. A single frame of the film was printed, magnified on super-contrast plates, whereby two identical plates were printed from each frame. With the use of a weak source of light and a Töpler, a parallel beam of light was created in the path of which both plates were placed. The light, passing through both plates, fell on an FEU-29 sensitive element, the signal from which, passing a discriminator, was transmitted to a potentiometer. The value of the signal on the potentiometer is proportional to the integral light flux which passed through the plates, and the value of the latter, in turn,

depends on the mutual distribution of the plates. In the case of the displacement of the plates the value of the signal changed and in this case a pen described a correlation curve on a moving tape. The average linear scale of temperature nonuniformities was calculated according to the correlation curve. A similar method and evaluation of error are presented in [6].

Analysis of the correlation curves obtained was performed in correspondence with [1]. Various scales of temperature nonuniformities were determined, corresponding to the real volume scales Λ_{burn} depending on the initial flow velocity V_{flow} and the fuel-air ratio.

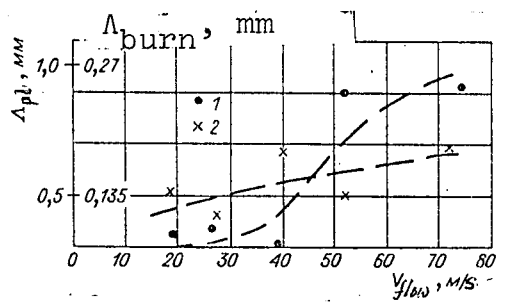


Fig. 5. Dependence of the scale of temperature nonuniformities on the initial velocity of a free-stream flow.
1- $x=68$ mm; 2- $x=188$ mm.

Figure 5 shows the dependence of the value of Λ_{burn} on the average initial flow velocity V_{flow} .

From the diagram it is apparent that there is a small tendency for Λ_{burn} to increase with an increase in V_{flow} . An analogous small change is observed even for the Lagrange turbulence scale according to experiments conducted according to the diffusion method.

With a decrease in the air-fuel ratio α or a corresponding /571 increase in the mean temperature at the end of the flame t_0 , some

increase in the scales of temperature nonuniformities Λ_{burn} (Fig. 6) is also observed. This is connected with the fact that the general level of temperatures in the flame increases and the region where ignition is possible expands within the limits of the given structural properties of the flow.

In the present study hydrogen was the fuel which was basically investigated, however in the case of burning such hydrocarbon fuels as kerosene and analogous distribution of zones with great temperature gradients, caused by the occurrence of chemical reactions and defined by the structure of the turbulent flow, was observed.

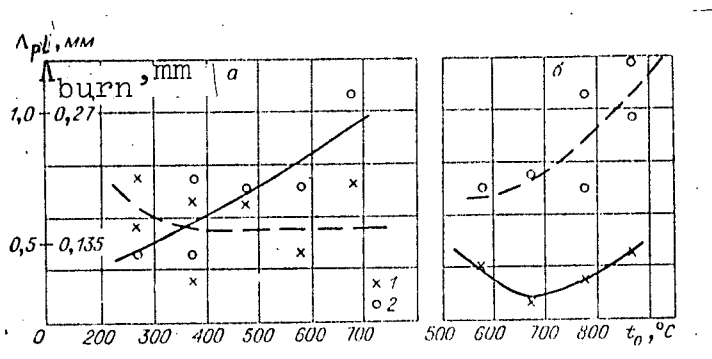


Fig. 6. Dependence of the scale of temperature nonuniformities on temperature. Average velocity of the free-stream flow 50-80 (a) and 100-120 m/s (b).

1- $x=75$ mm; 2- $x=100$ mm.

This was shown in the case of burning dispersed kerosene in an intensively turbulized flow, when the drops were in an evaporation mode [2]. The above-mentioned experiments give rise to the hope of connecting the localized zones with the structure of the flow in a number of other systems and may be used for constructing a calculation diagram of the burn-out of a diffusion flame, considering this property.

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